Earth's Climate System: A 21st Century Grand Challenge

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Carnegie Capital Science Lectures
Centennial Season 2001-2002
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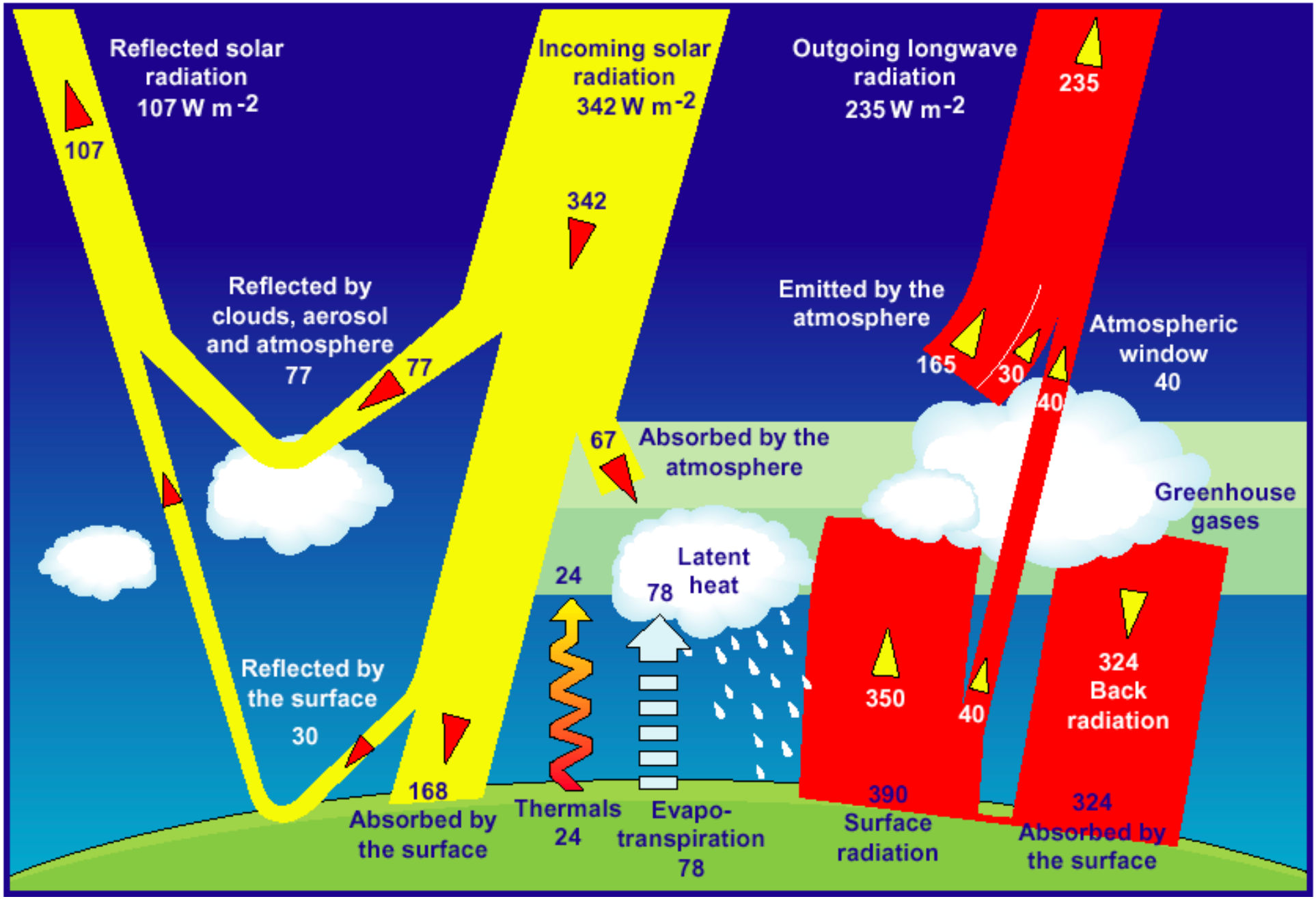
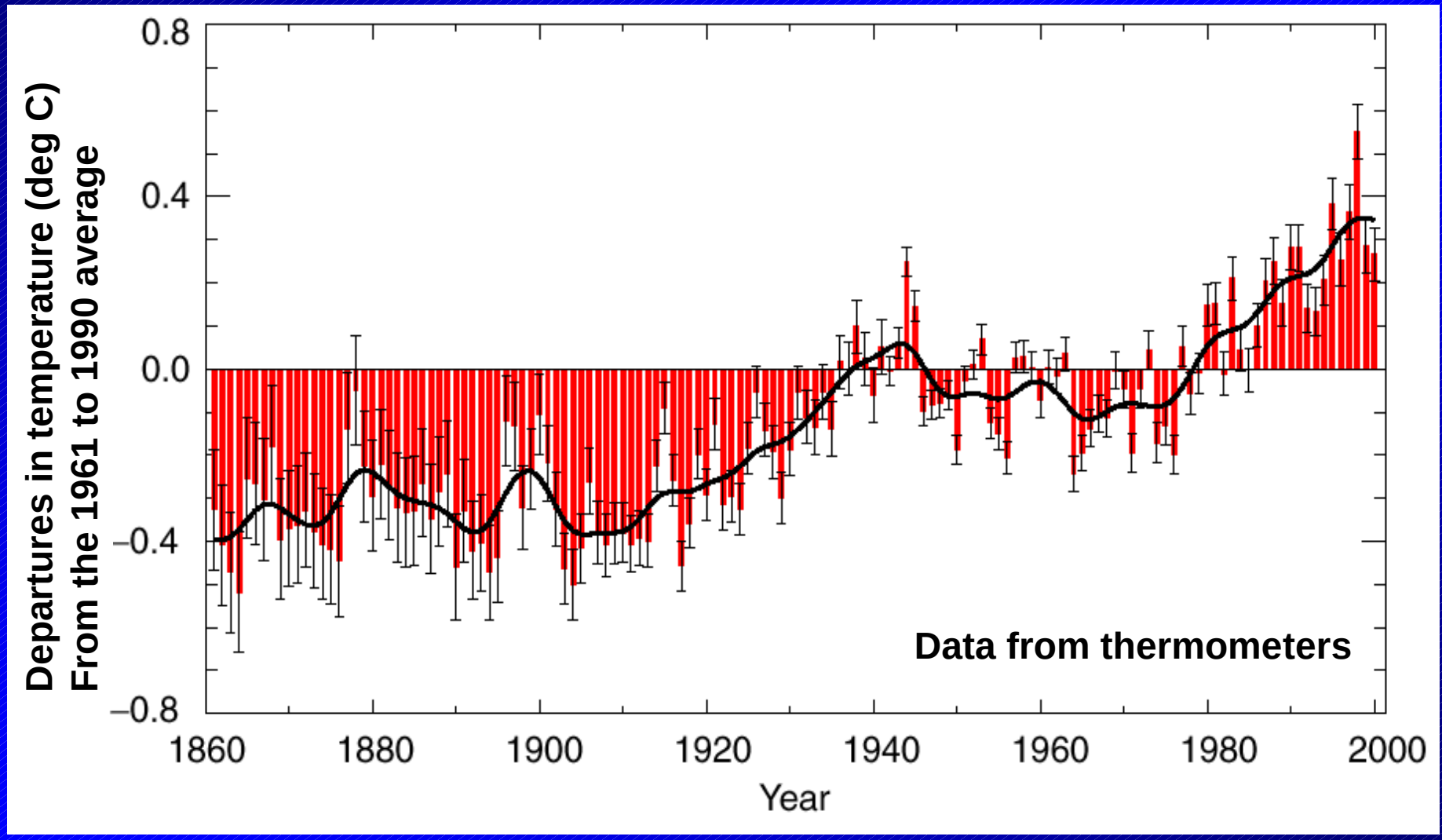
There are many ways to view the Earth…..

With different stories to tell….

Climate System Energy Balance

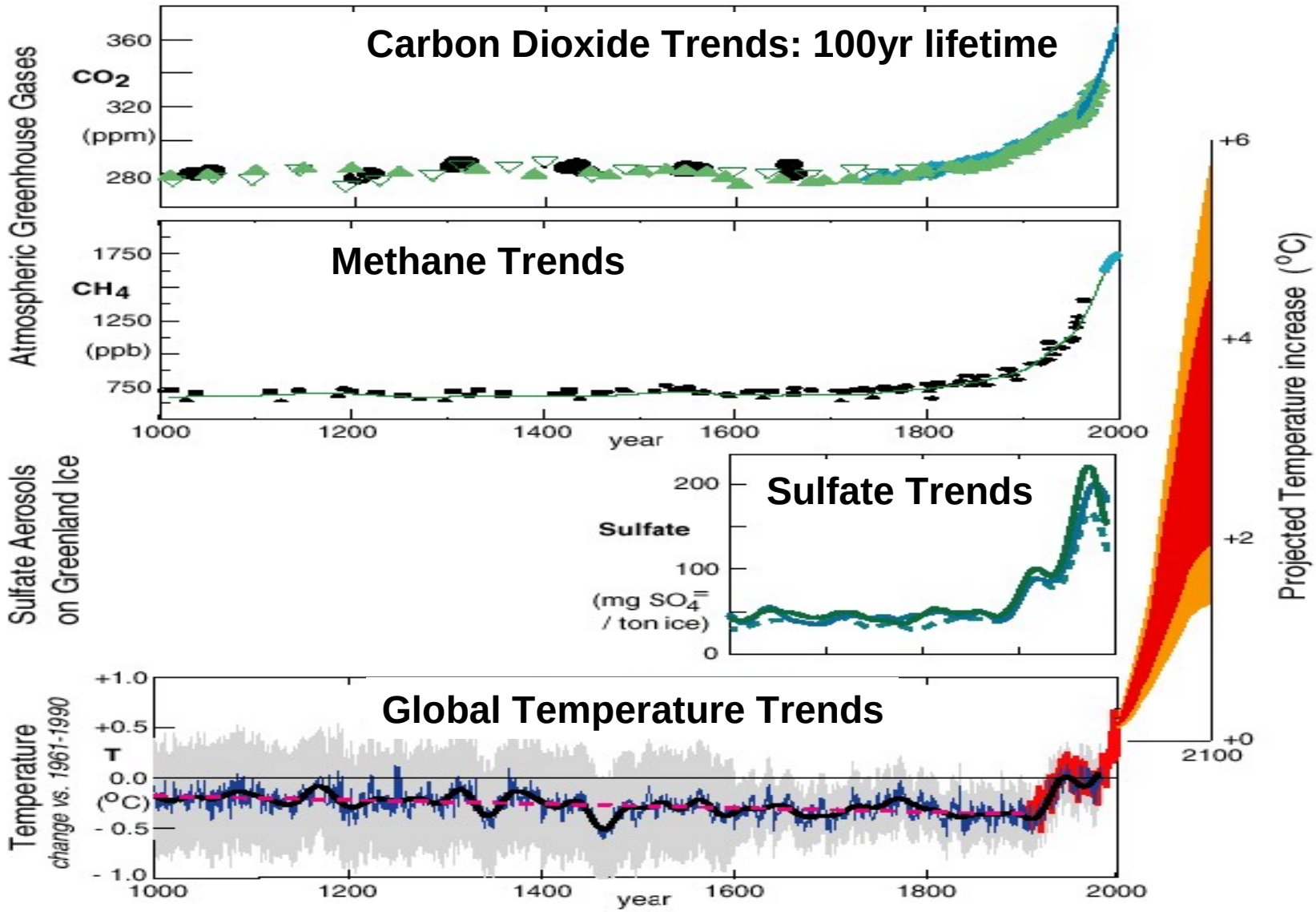


What global surface temperature change has occurred so far?



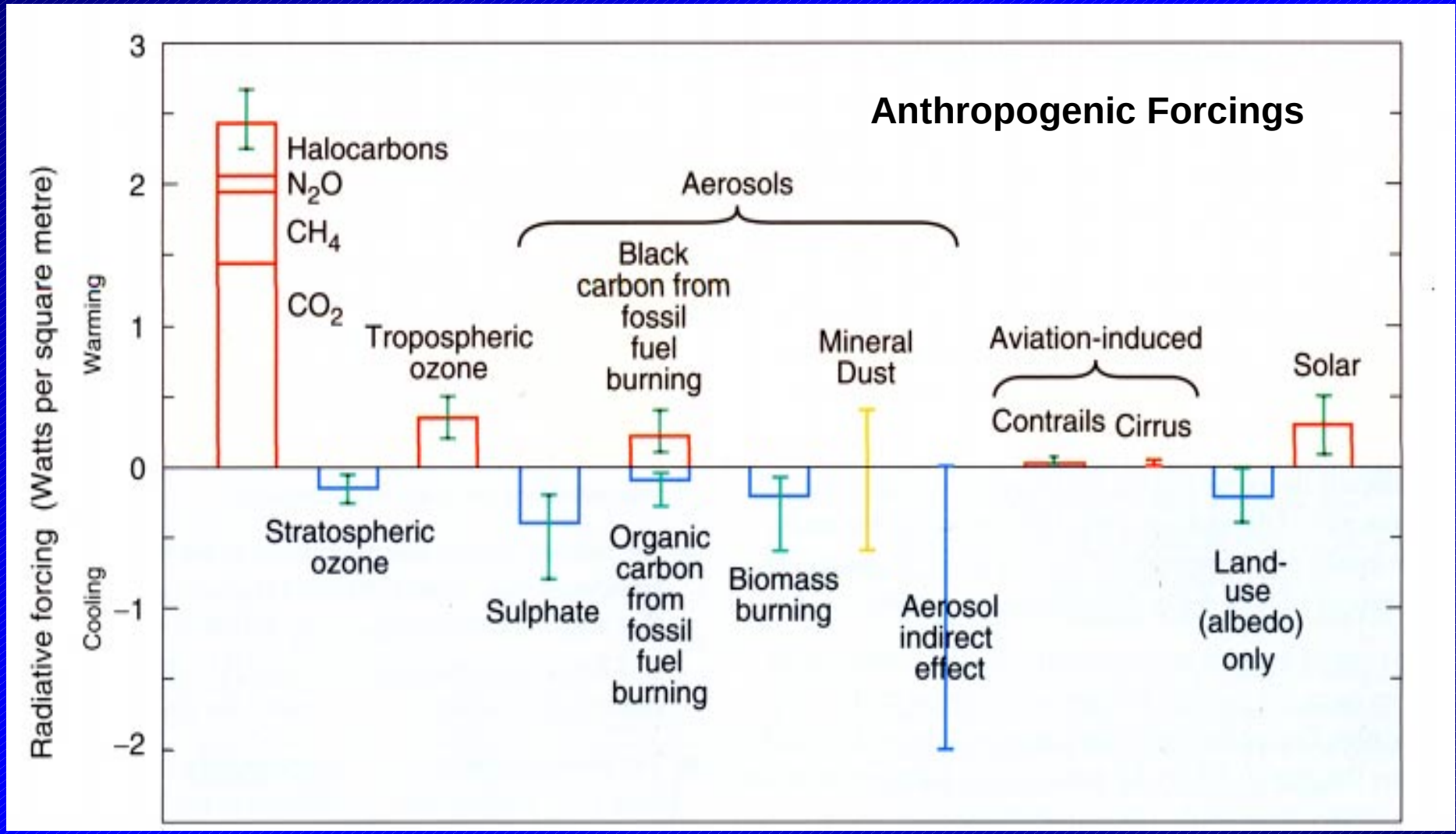
IPCC 2001

Human Influence on Climate



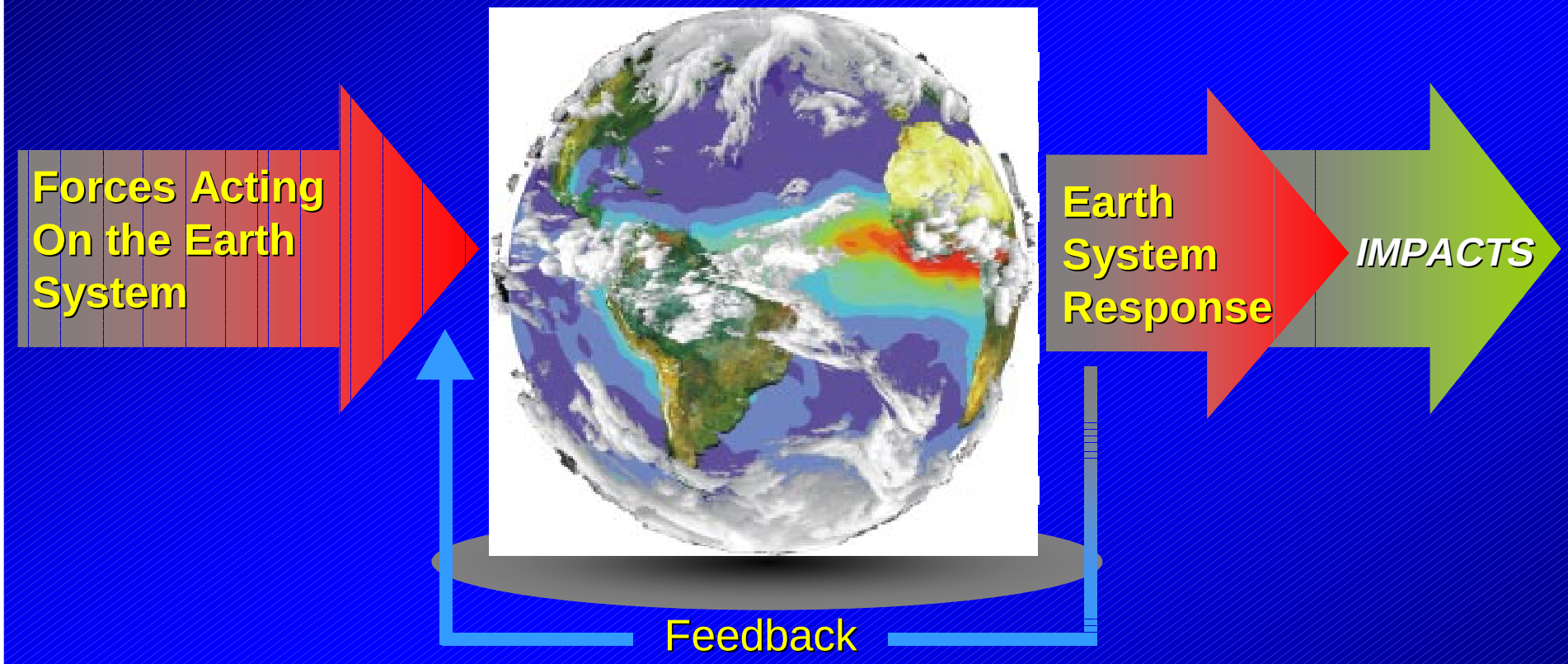
From M. Prather University of California at Irvine

Radiative Forcing from 1750 to 2000



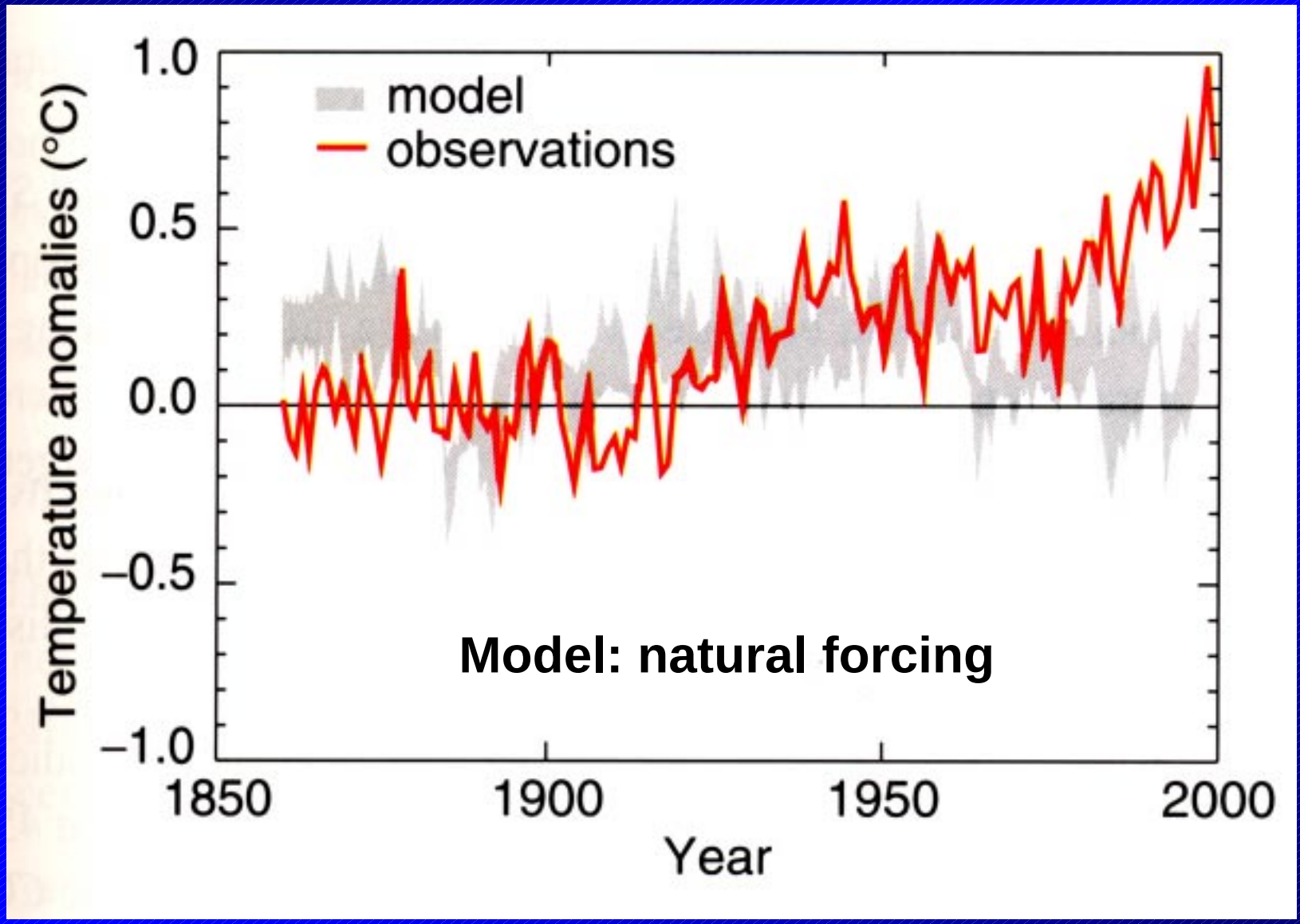
IPCC, 2001

How does the Earth Respond?



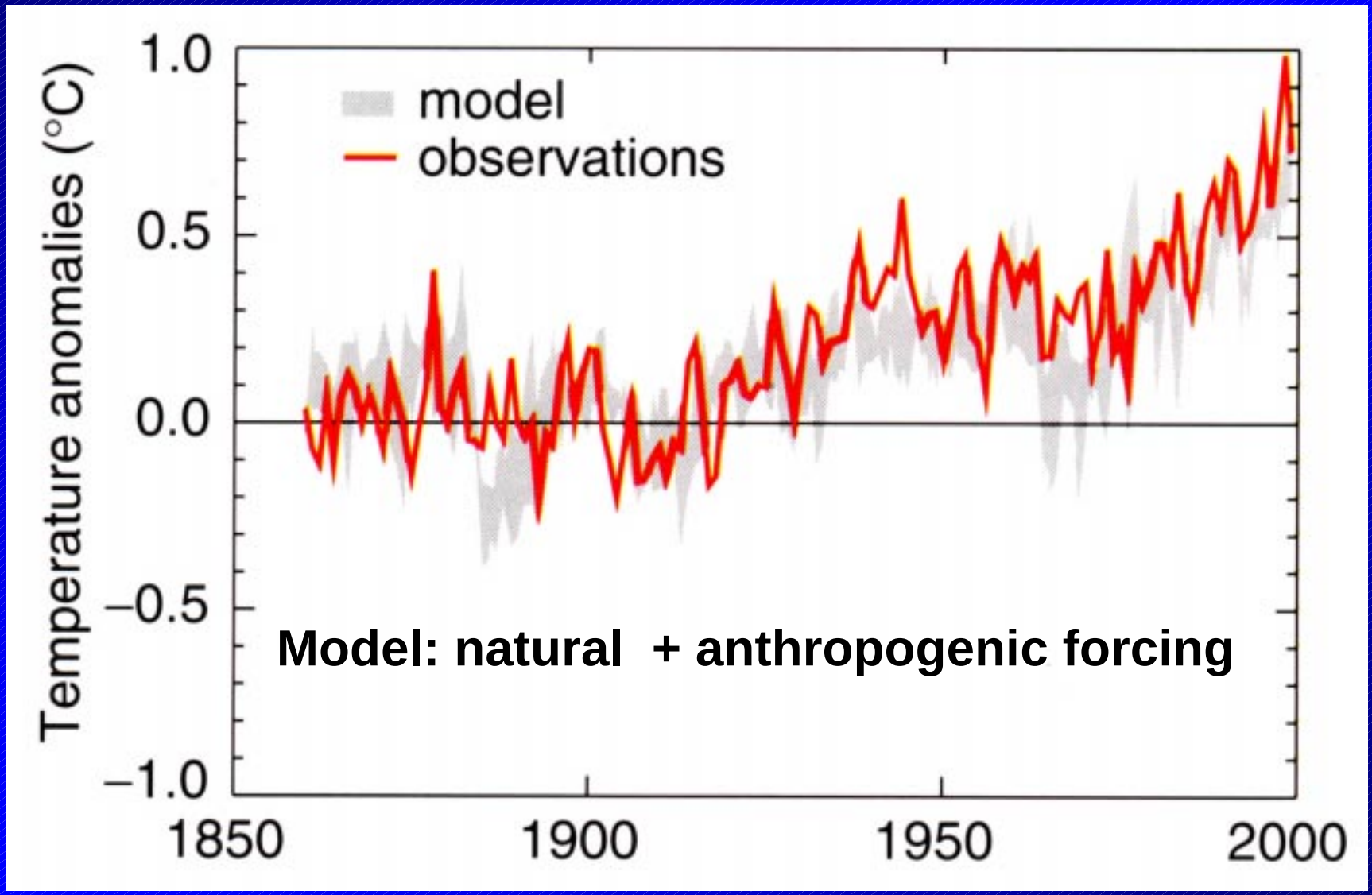
Of the total forcing of the climate system, 40% is due to the direct effect of greenhouse gases and aerosols, and 60% is from feedback effects, such as increasing concentrations of water vapor as temperature rises.

Global Temperature Predictions



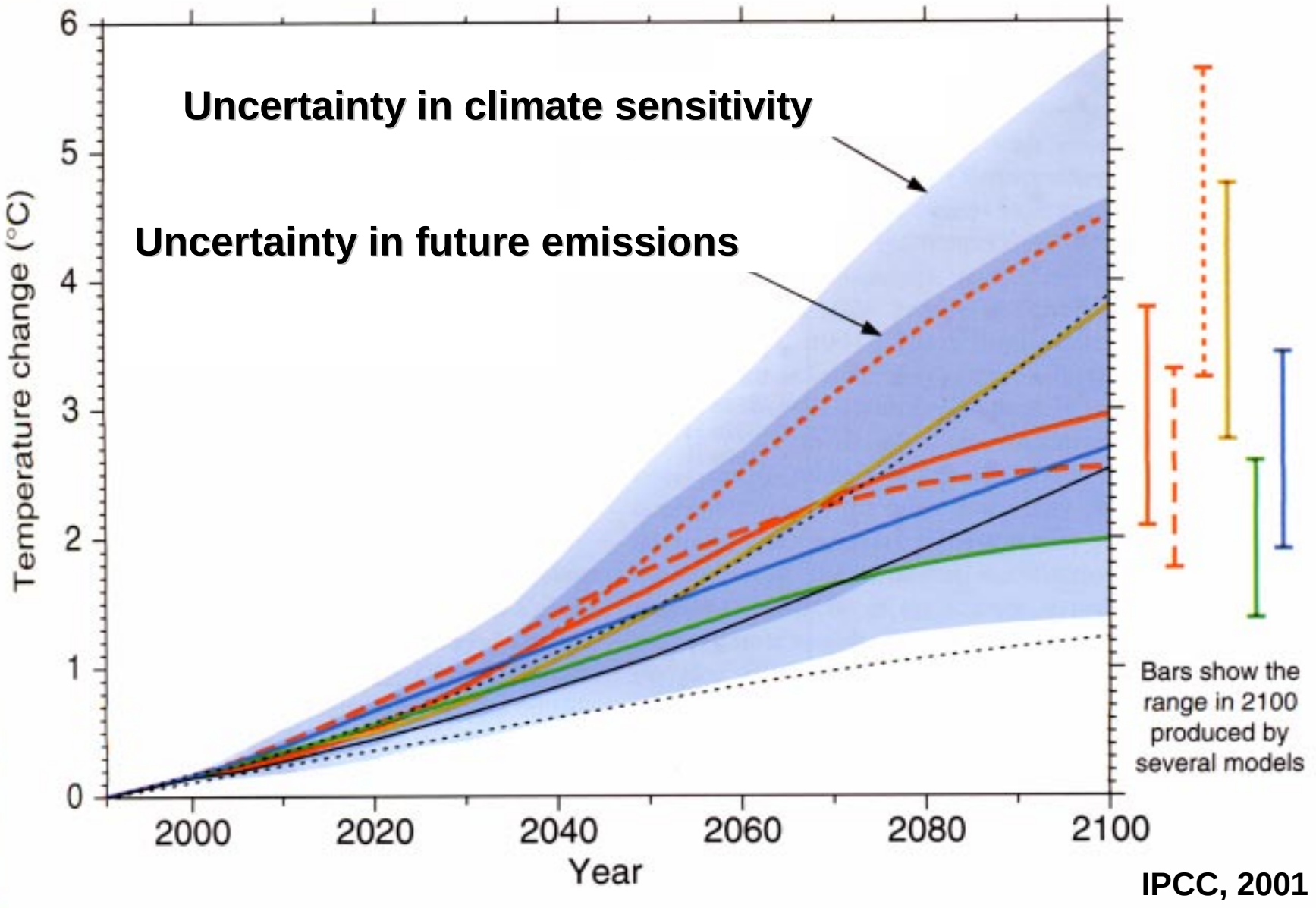
IPCC, 2001

Global Temperature Predictions



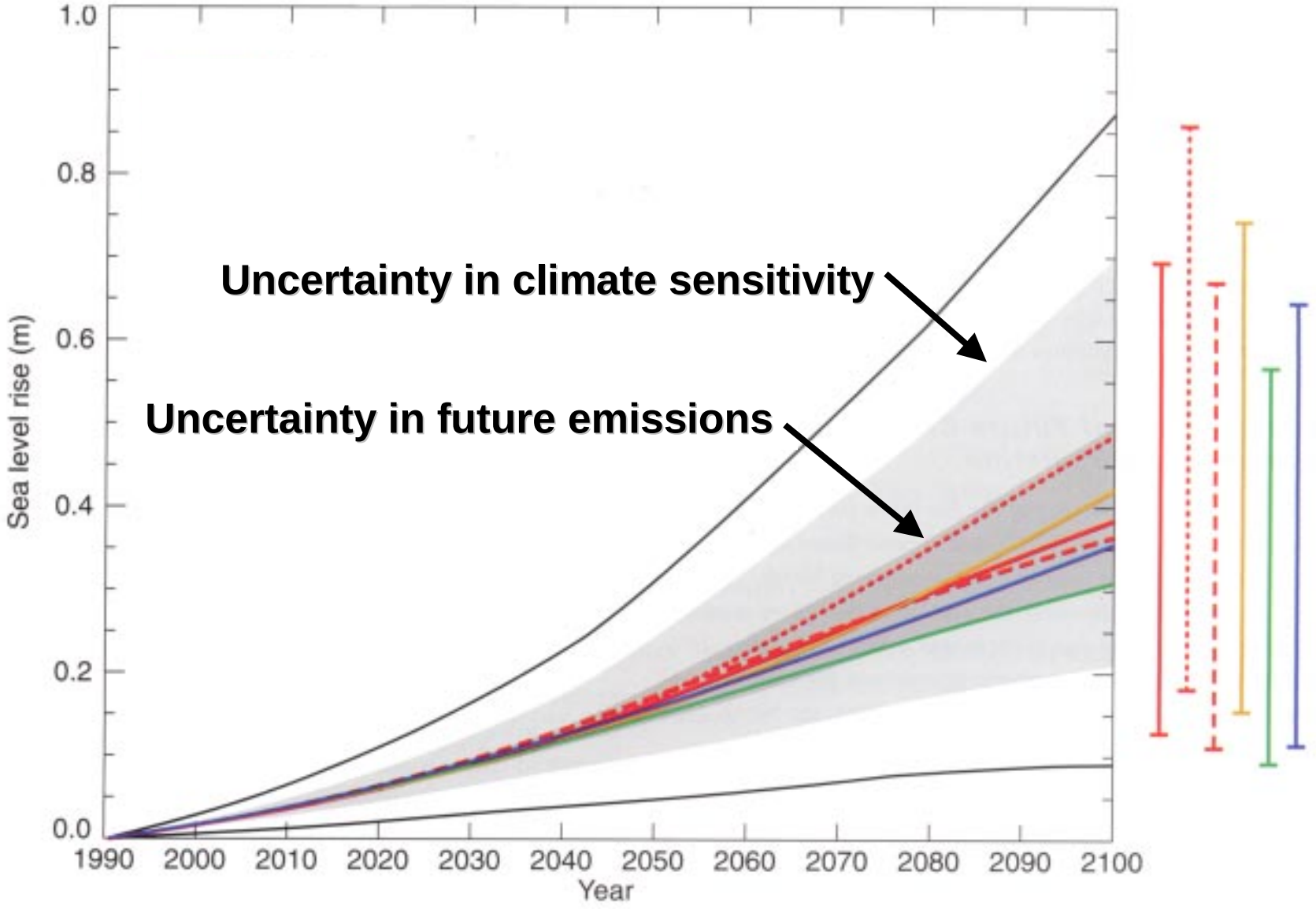
IPCC, 2001

Global Temperature Predictions



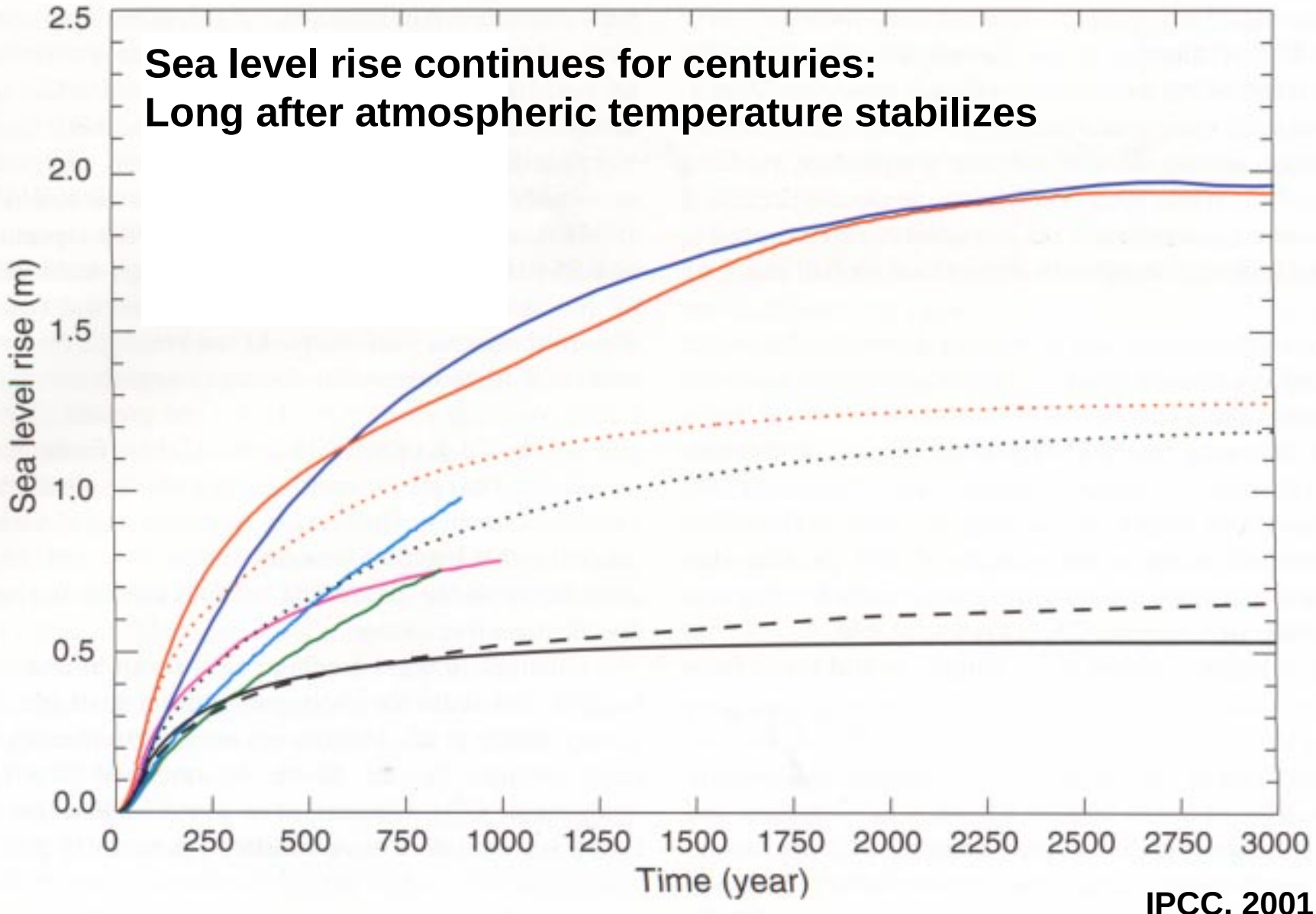
IPCC, 2001

Predicted Sea Level rise from 1990 to 2100



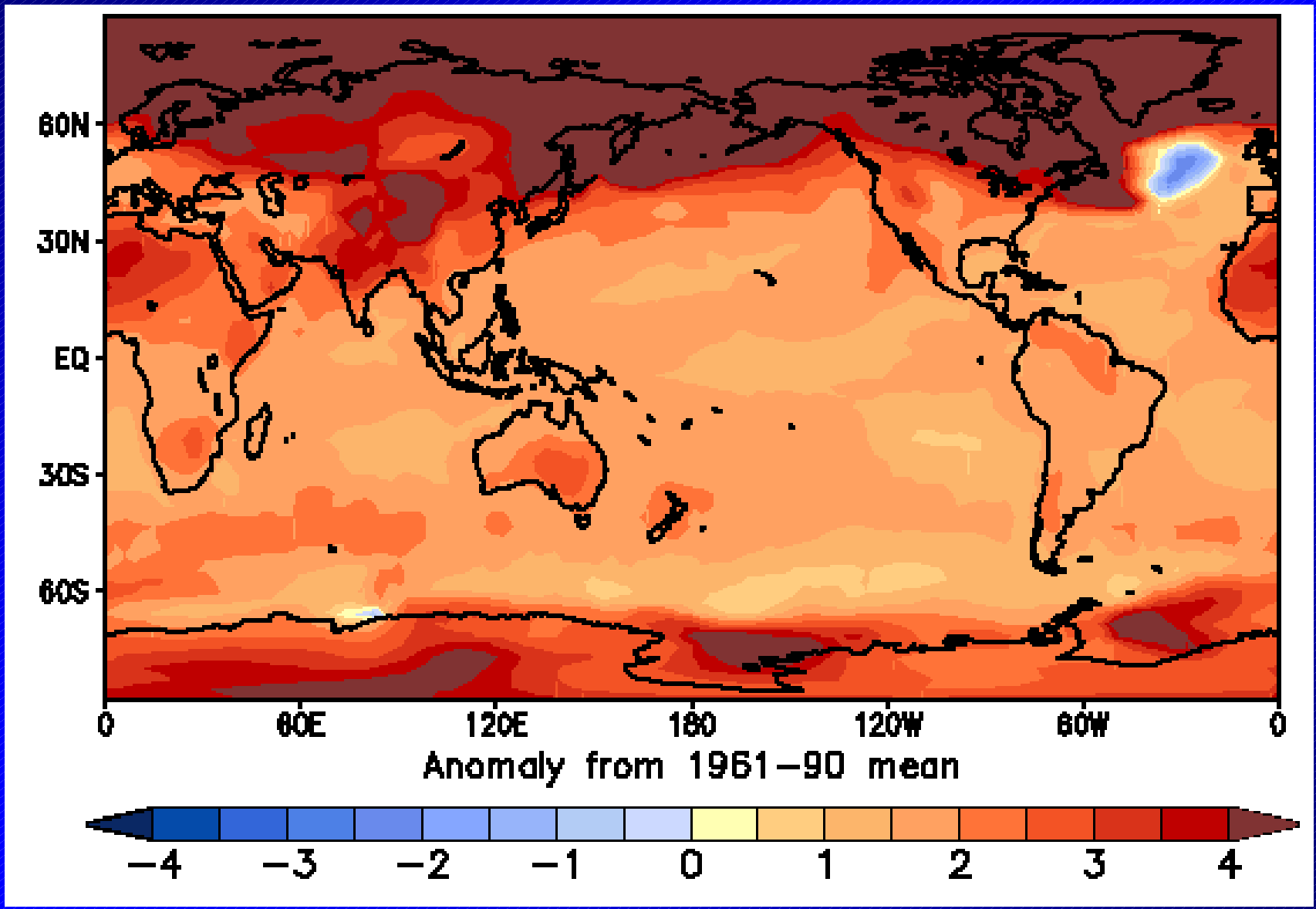
IPCC, 2001

Climate Model Sea Level Predictions

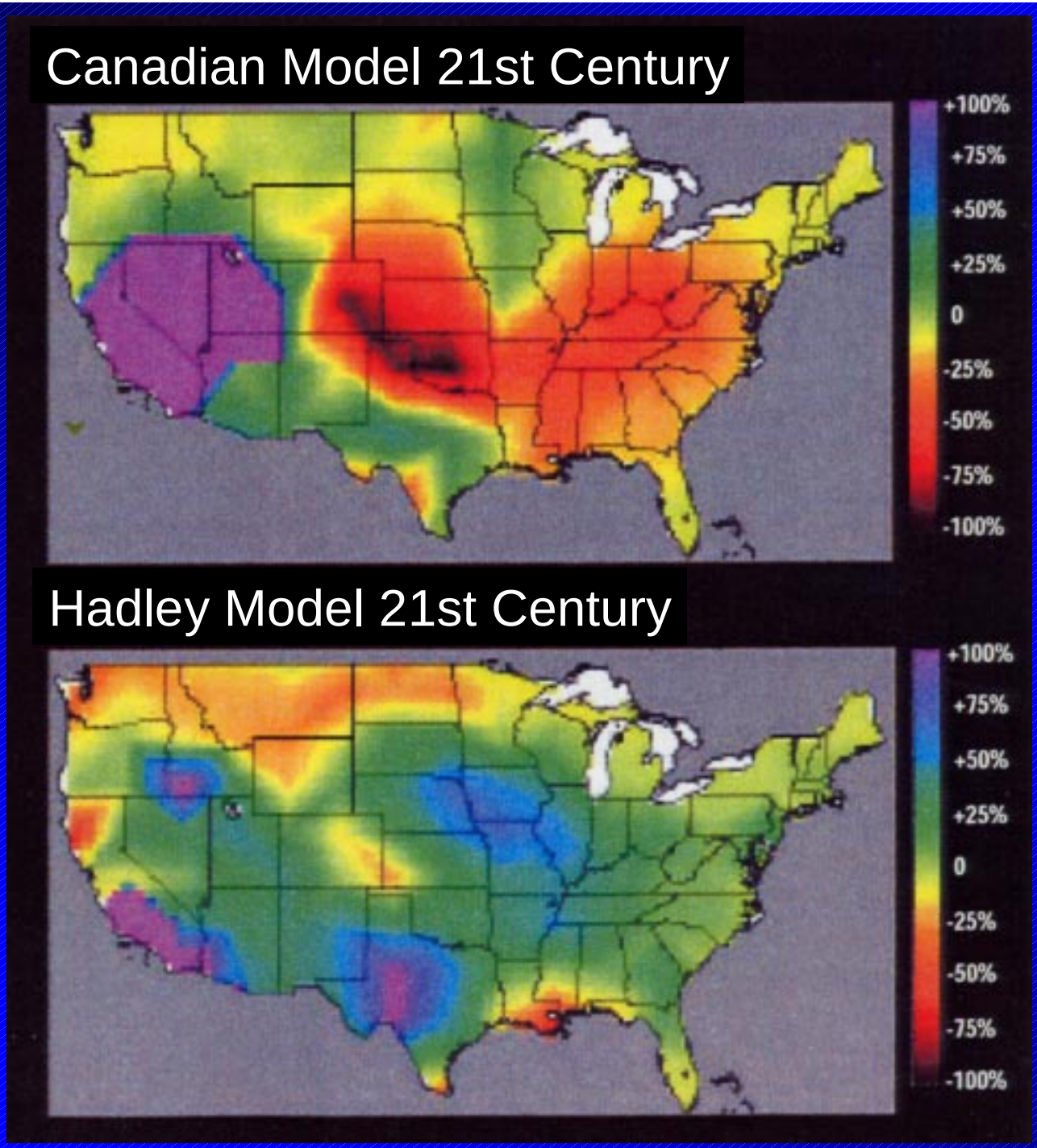


IPCC, 2001

Example 2100 Climate Model Prediction: Baseline Scenario (Anomaly in Deg C)



Courtesy Warren Washington, NCAR



U.S. summer soil moisture predictions:

A tale of two climate models…

…and of large regional uncertainties.

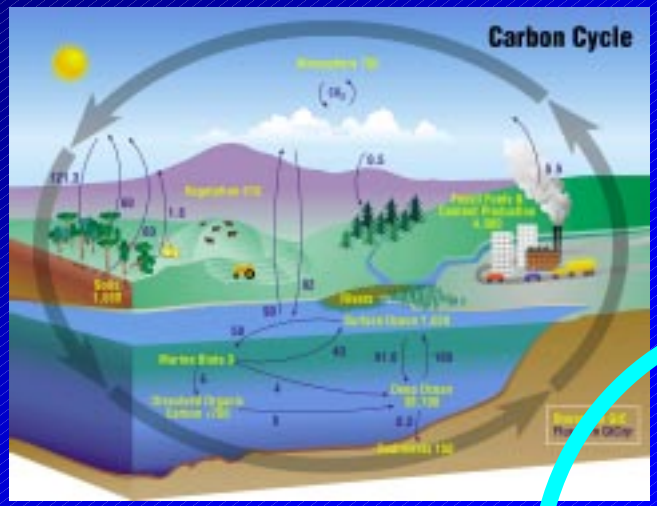
What is Climate?

- **Climate is the long term average of weather.**
  - ***14-day weather prediction limit:***
    but no known limit to climate prediction.
  - ***Weather data accuracy is 1 degree,***
    but climate accuracy is 0.1 degree:
    a factor of 10 tougher measurement.

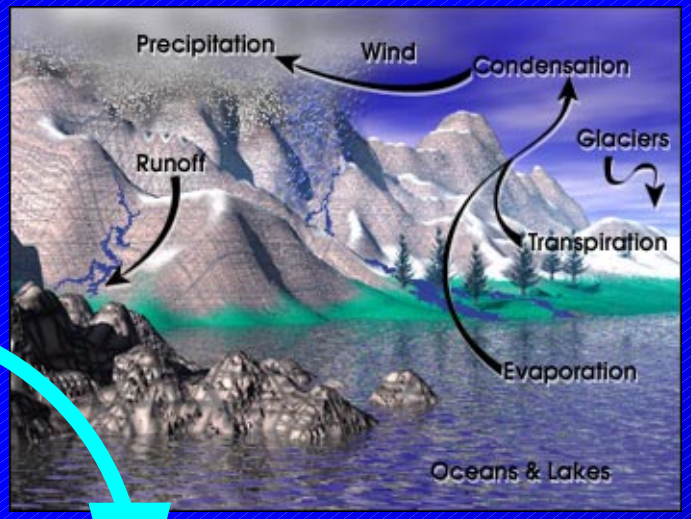
What is a computer model of the climate system?

Major Climate System Elements

Carbon Cycle

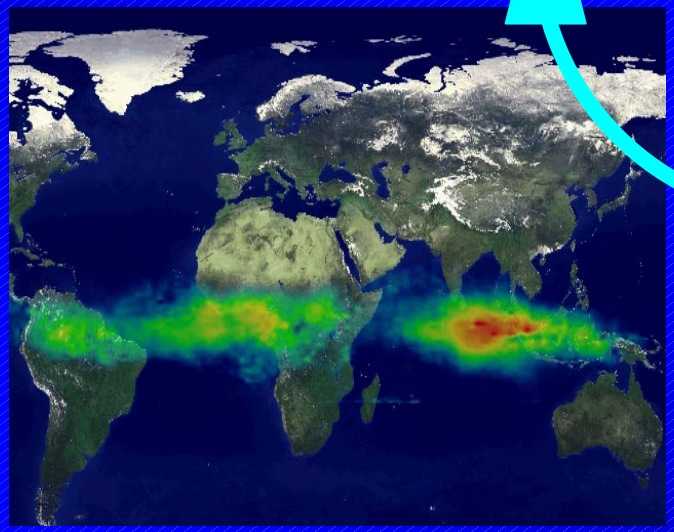


Water & Energy Cycle

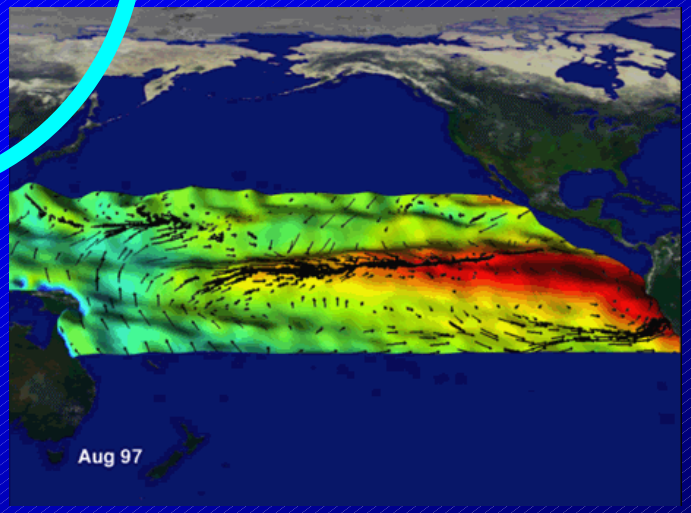


Coupled Chaotic Nonlinear

Atmospheric Chemistry



Atmosphere and Ocean Dynamics



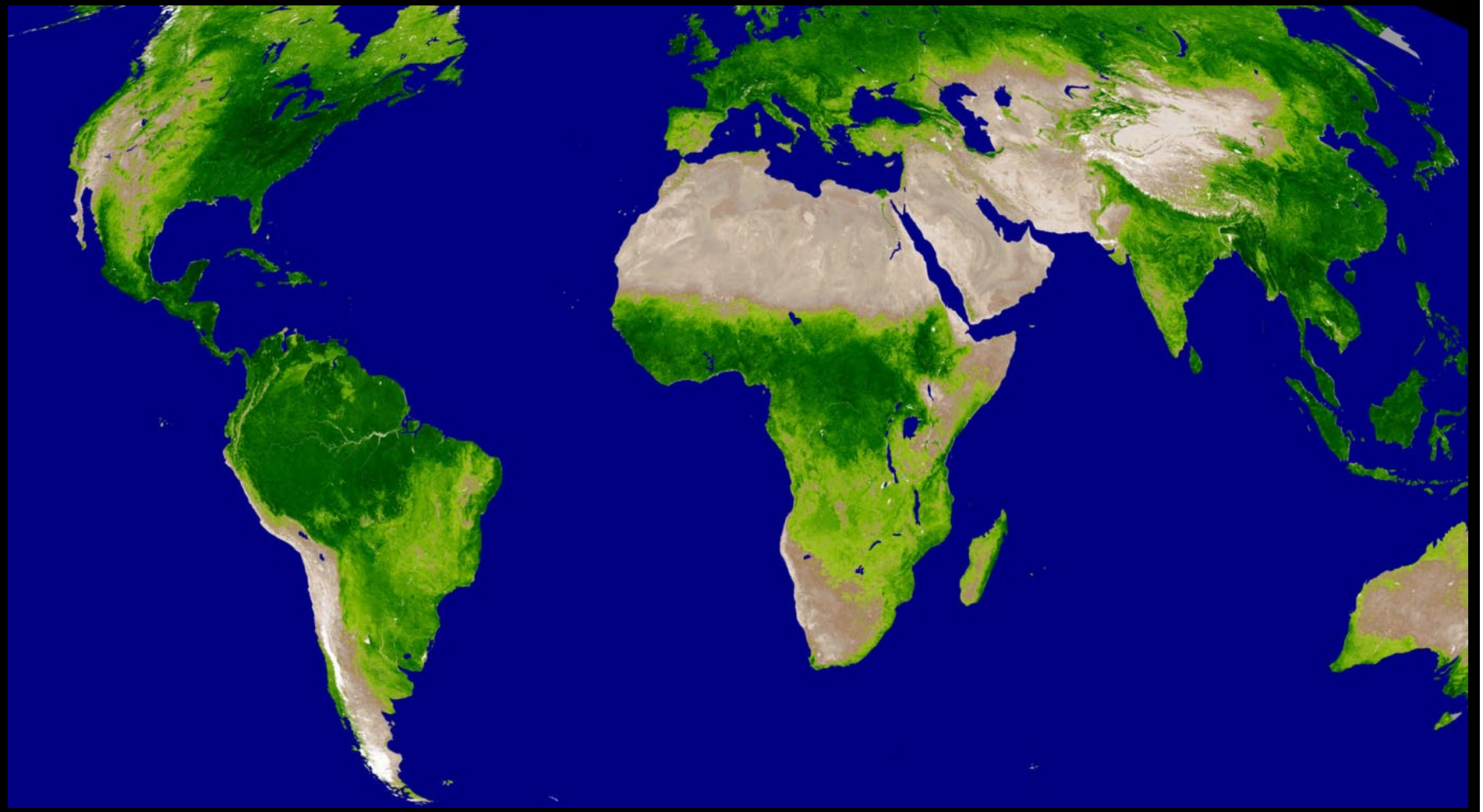
How can we use observations to test and improve climate models?

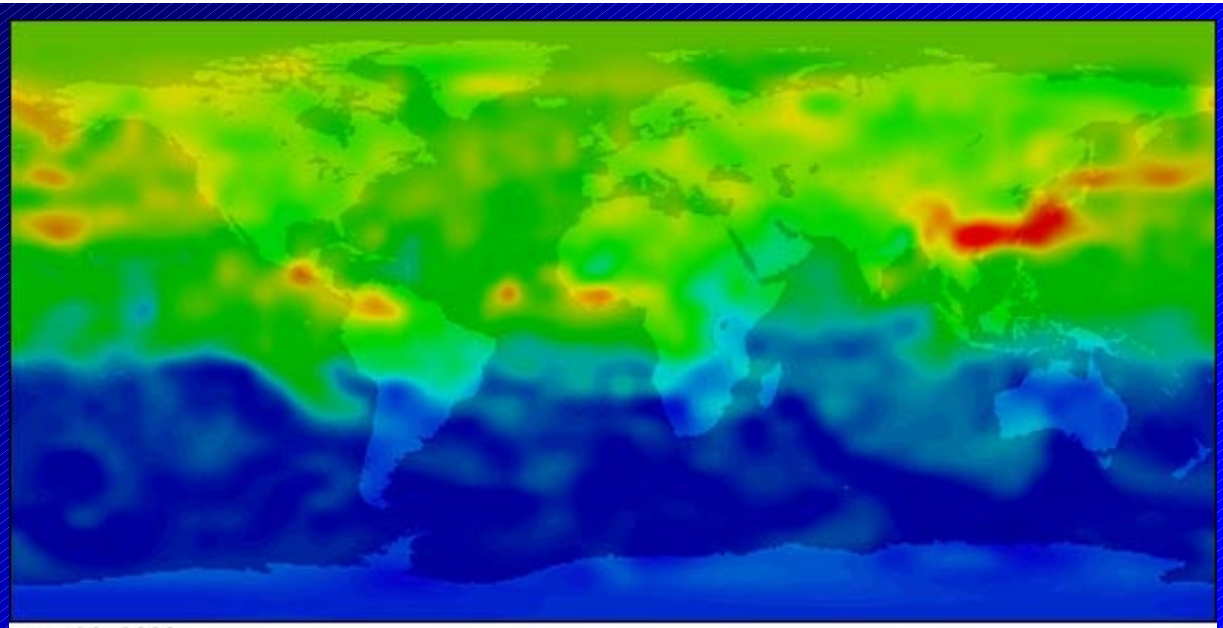
NASA Has Engaged in Earth Science From the Very Beginning

TIROS IX mosaic, February 13, 1965

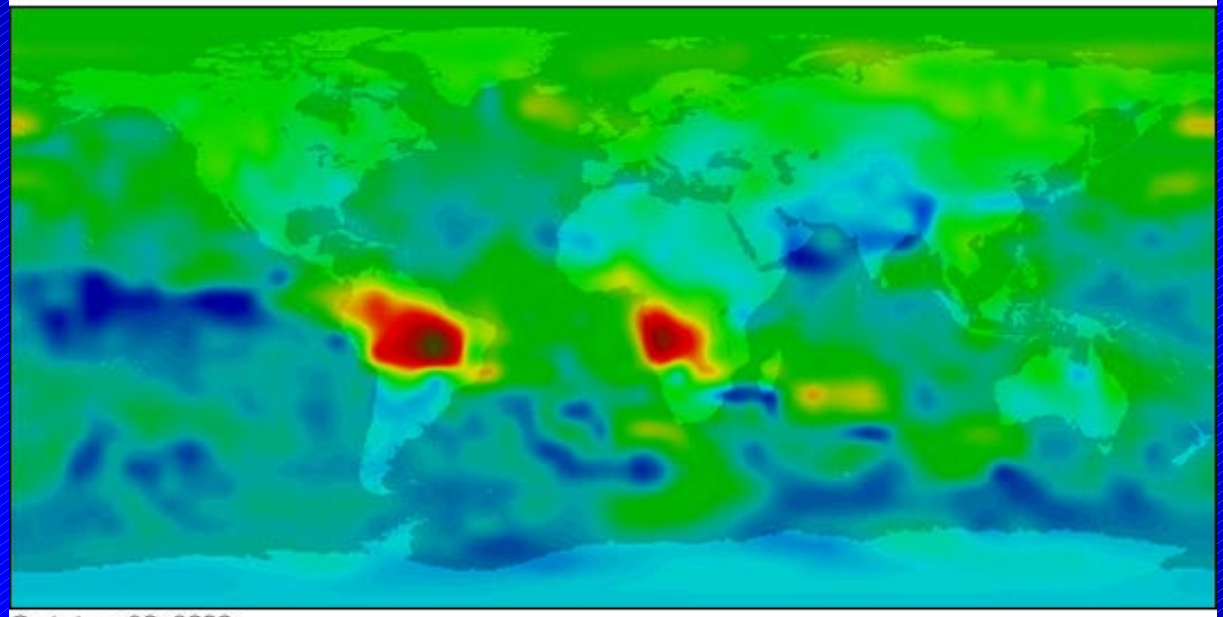
Earth View From MODIS on the Terra Spacecraft 2001

Vegetation from MODIS on Terra
Summer, 2001





April 30, 2000



October 30, 2000

Carbon Monoxide Concentration (parts per billion)

50 220 390

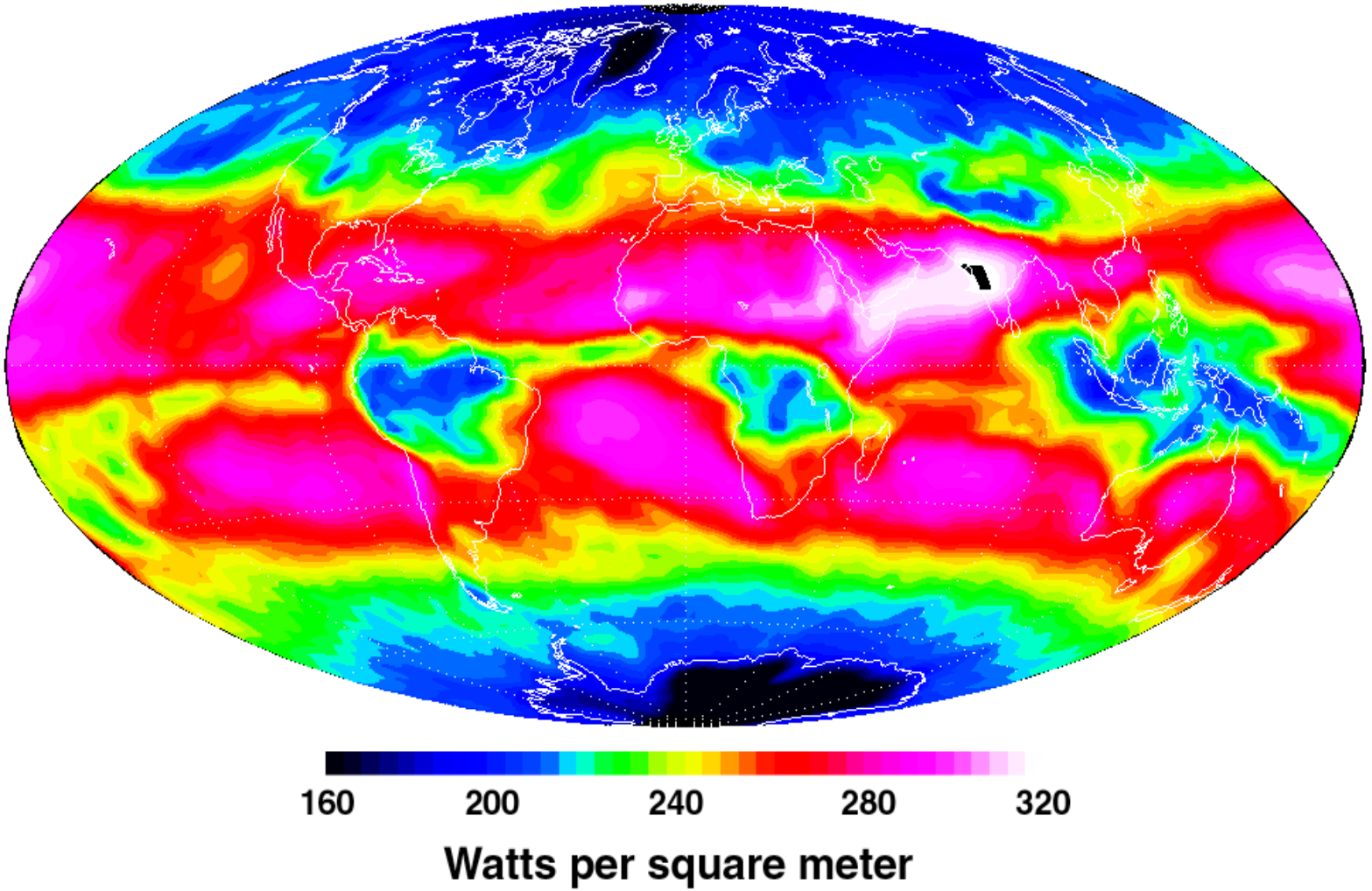
Carbon Monoxide

MOPPITT On Terra

April & October 2000

Unprecedented Accuracy of new EOS Radiation Data

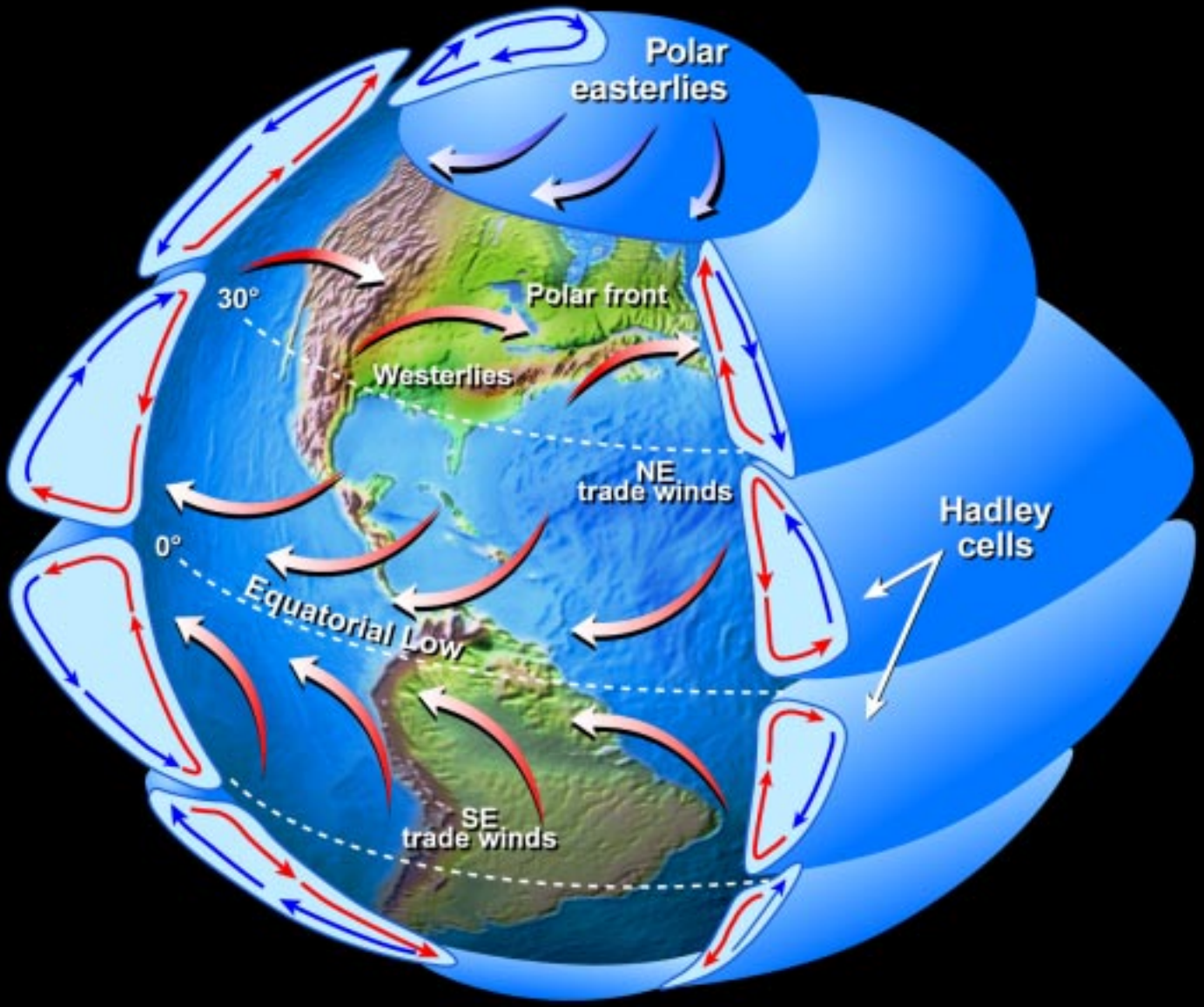
Emitted Thermal Flux Measured By CERES
Terra March 2000



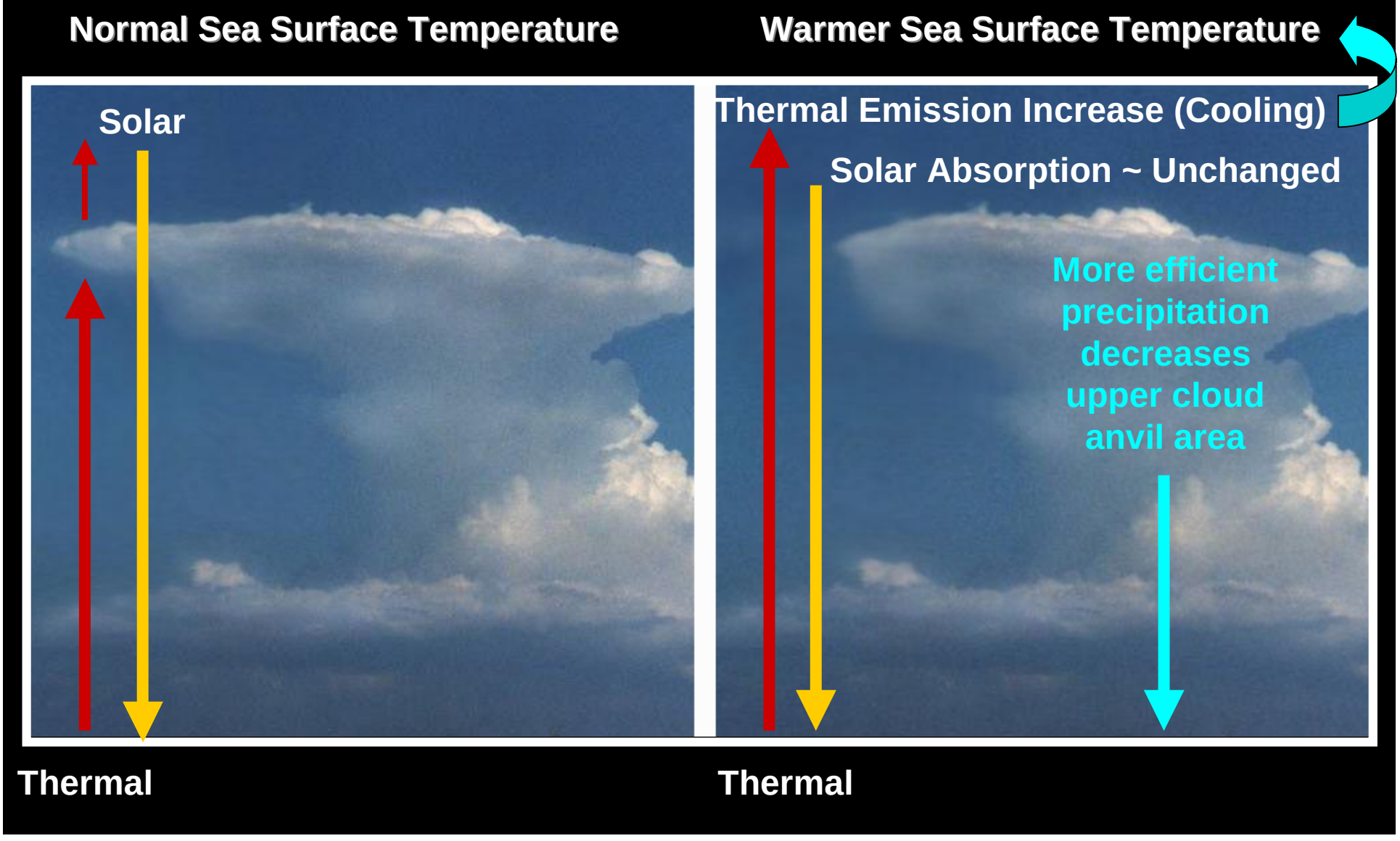
Early NASA EOS Satellite Results On the Role of Clouds in Climate

- *Focus on the Tropics*
- *What about the recent Iris hypothesis?*
- *Was the 1997/98 El Nino really different?*
- *Is there evidence for decadal change?*

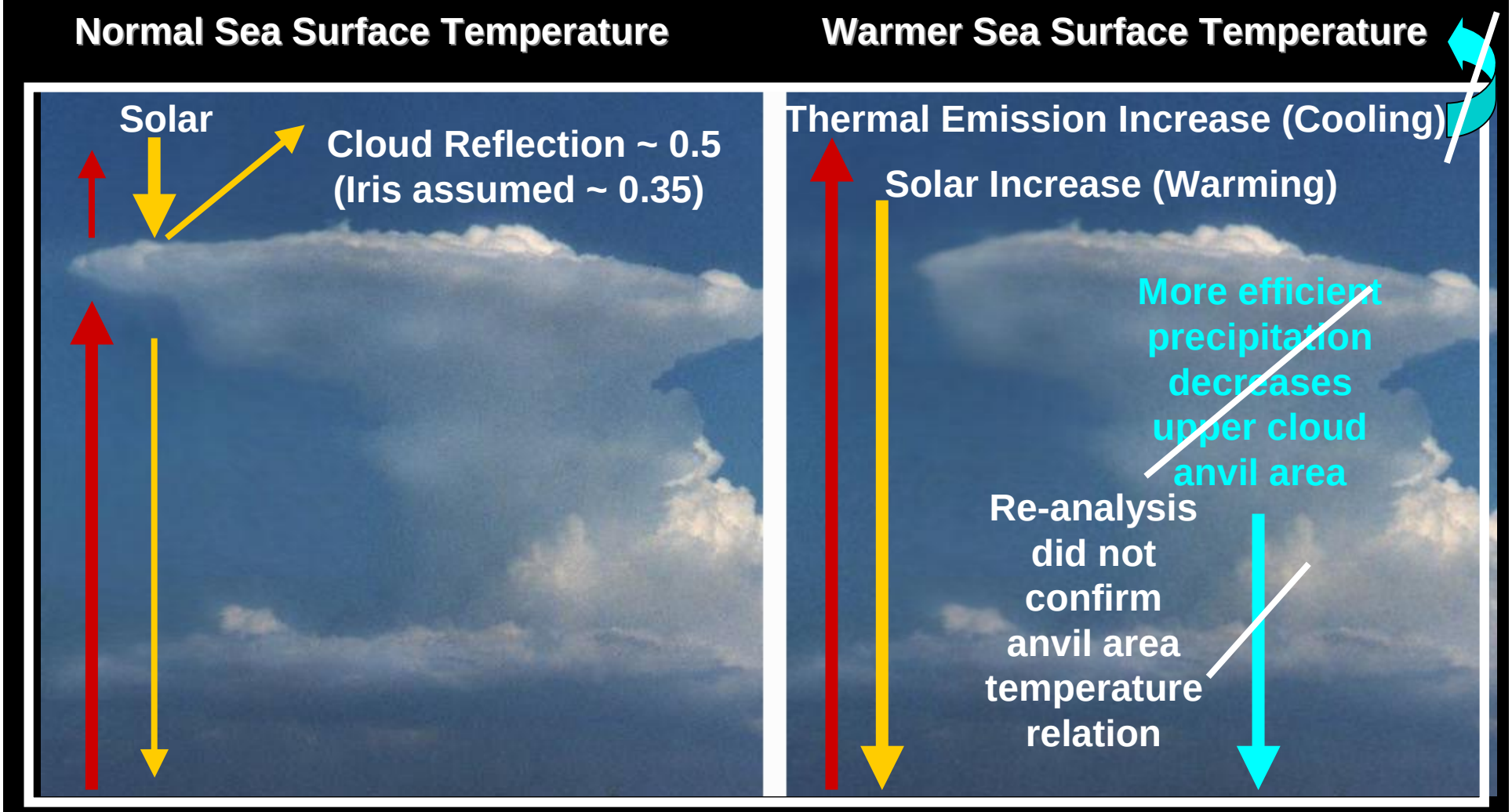
Global Atmospheric Circulation



The Iris Cloud Feedback Concept



The Iris: New Observations Reject

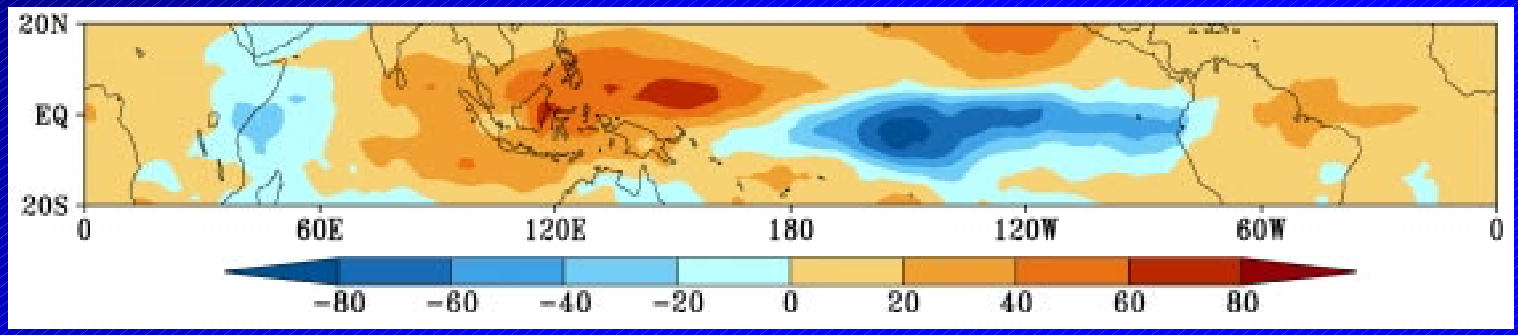


The dramatic 1997/98 El Nino

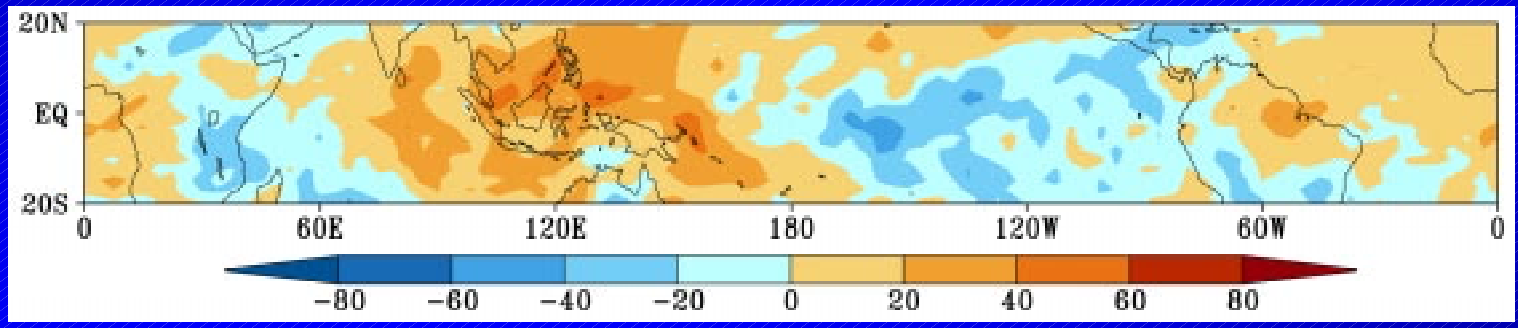
- Rivaled only by the 1983 El Nino during the last century.
- First useful climate prediction using ocean and atmosphere observing systems
- Can we use it as a test of short term climate as well as the effects of clouds on long-term climate change?

Jan/Feb 98 El Nino Thermal Flux Anomalies

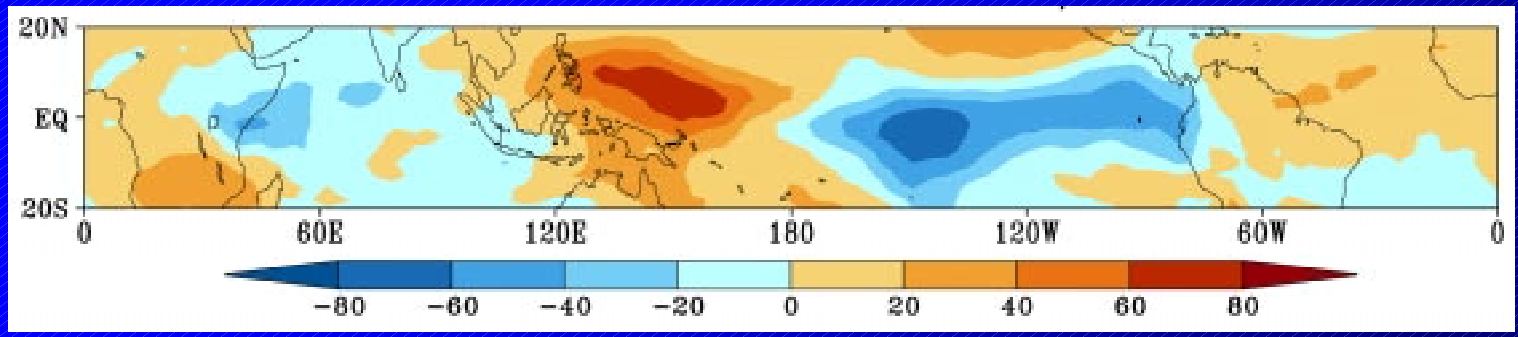
NASA CERES Radiation Observations



NOAA GFDL Standard Climate Model

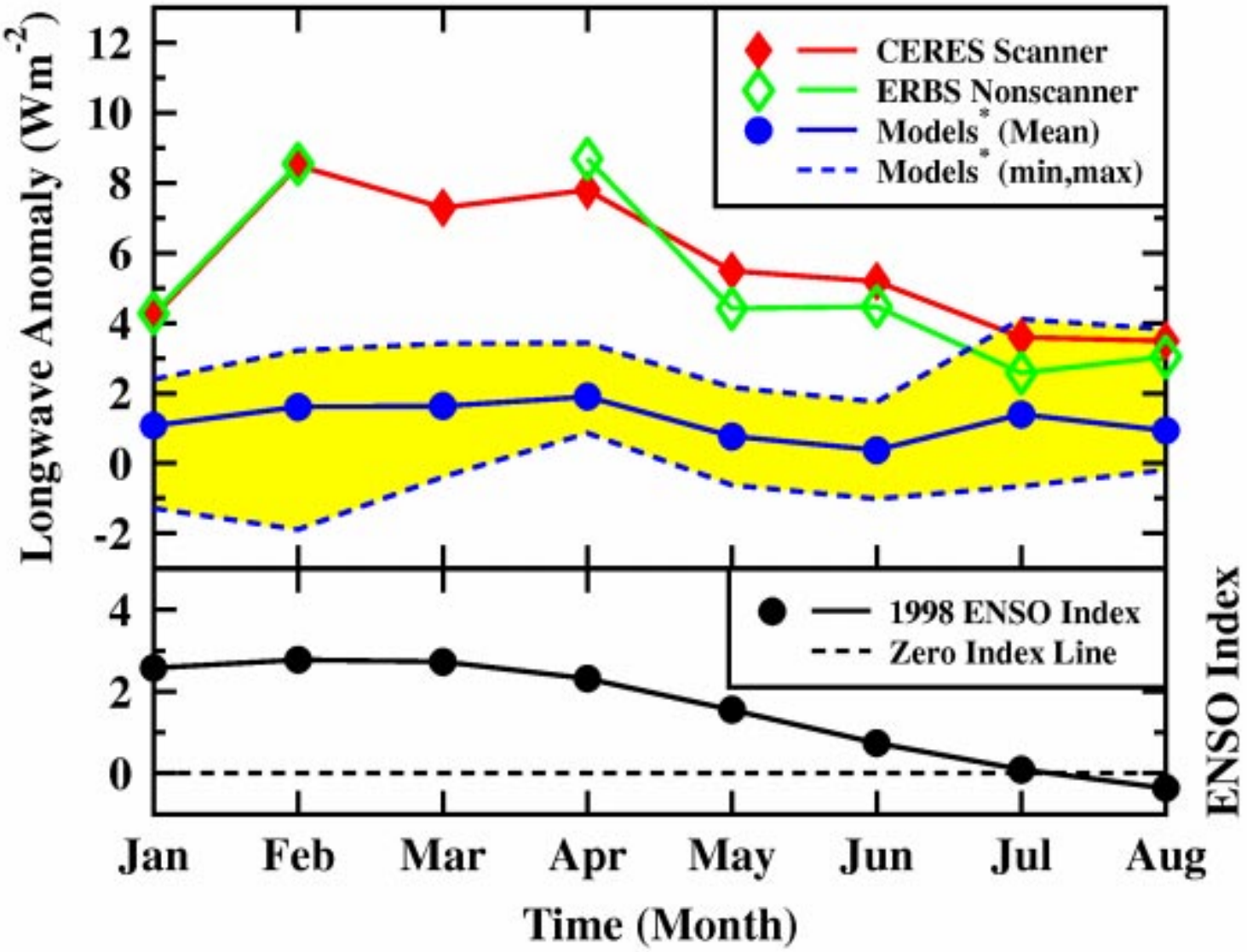


NOAA GFDL Experimental Prediction Model



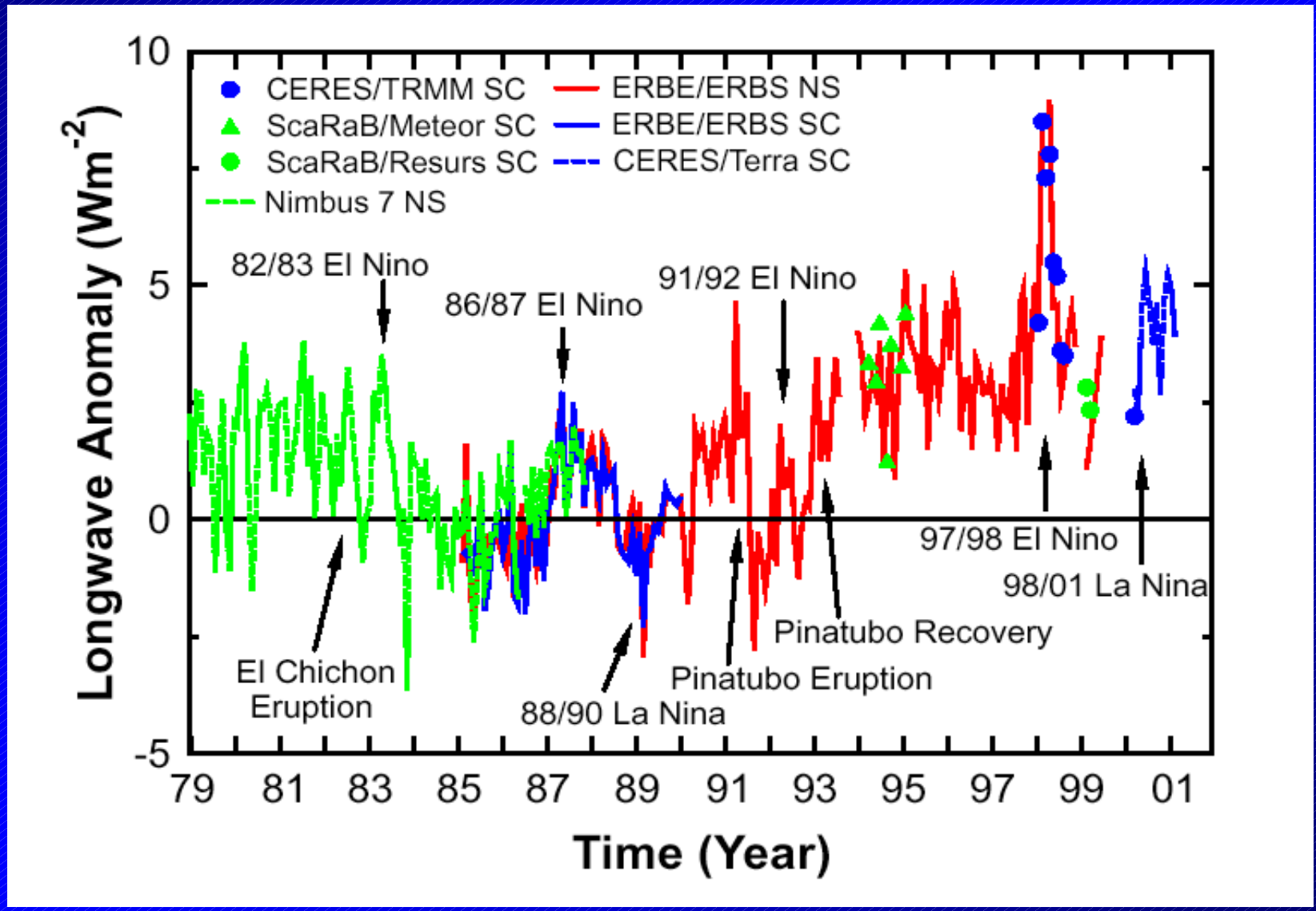
1998 El Nino Tropical Mean (20S - 20N) Longwave Flux Anomalies

(Anomalies Referenced to 1985 through 1989 Baseline)

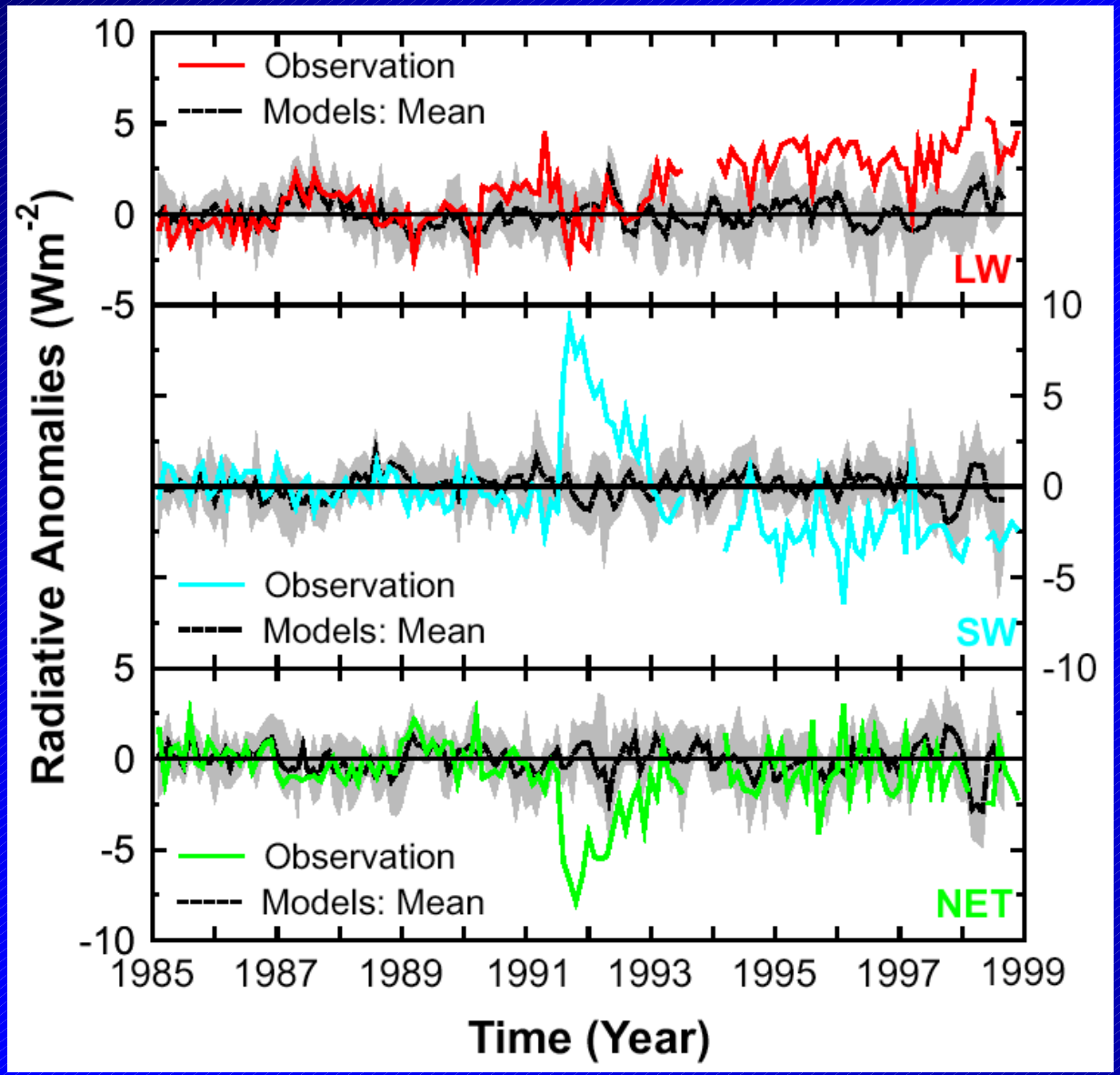


*5 Climate Models and NCEP Re-analysis; All used observed SSTs; Climate Models: NCAR-CSM (Kiehl) UKMO (Allan, Slingo), GFDL and GFDL-EP (Soden, Gordon), CSU (Randall)

An overlapping Earth radiation climate record: 22 years from Nimbus 7 to Terra.



Comparison of Observed Decadal Tropical Radiation Variation with Current Climate Models



LW:
Emitted Thermal Fluxes

SW:
Reflected Solar Fluxes

Net:
Net Radiative Fluxes

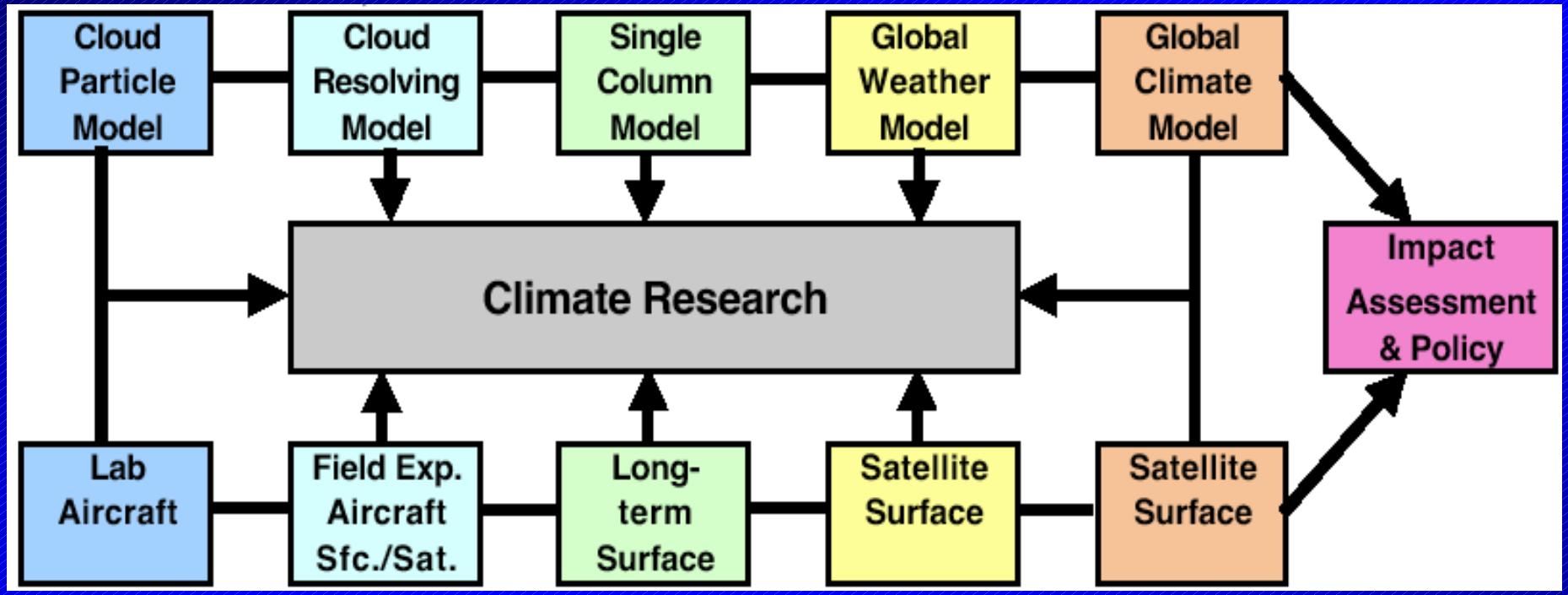
Models less variable than the observations:
- missing feedbacks?
- missing forcings?
- clouds physics?

Why are clouds so tough?

- Aerosols <0.1micron, cloud systems >1000 km
- Cloud particles grow in seconds: climate is centuries
- Cloud growth can be explosive:
  1 thunderstorm packs the energy of an H-bomb.
- Cloud properties can vary a factor of 1000 in hours.
- Few percent cloud changes drive climate sensitivity
- Best current climate models are 250km scale
- Cloud updrafts are a 100m to a few km.
- A climate model resolving all cloud physics down to aerosol scale would require 10^{38} supercomputers: 190 years of current Moore's Law rate of advance.

How can we improve in the future?

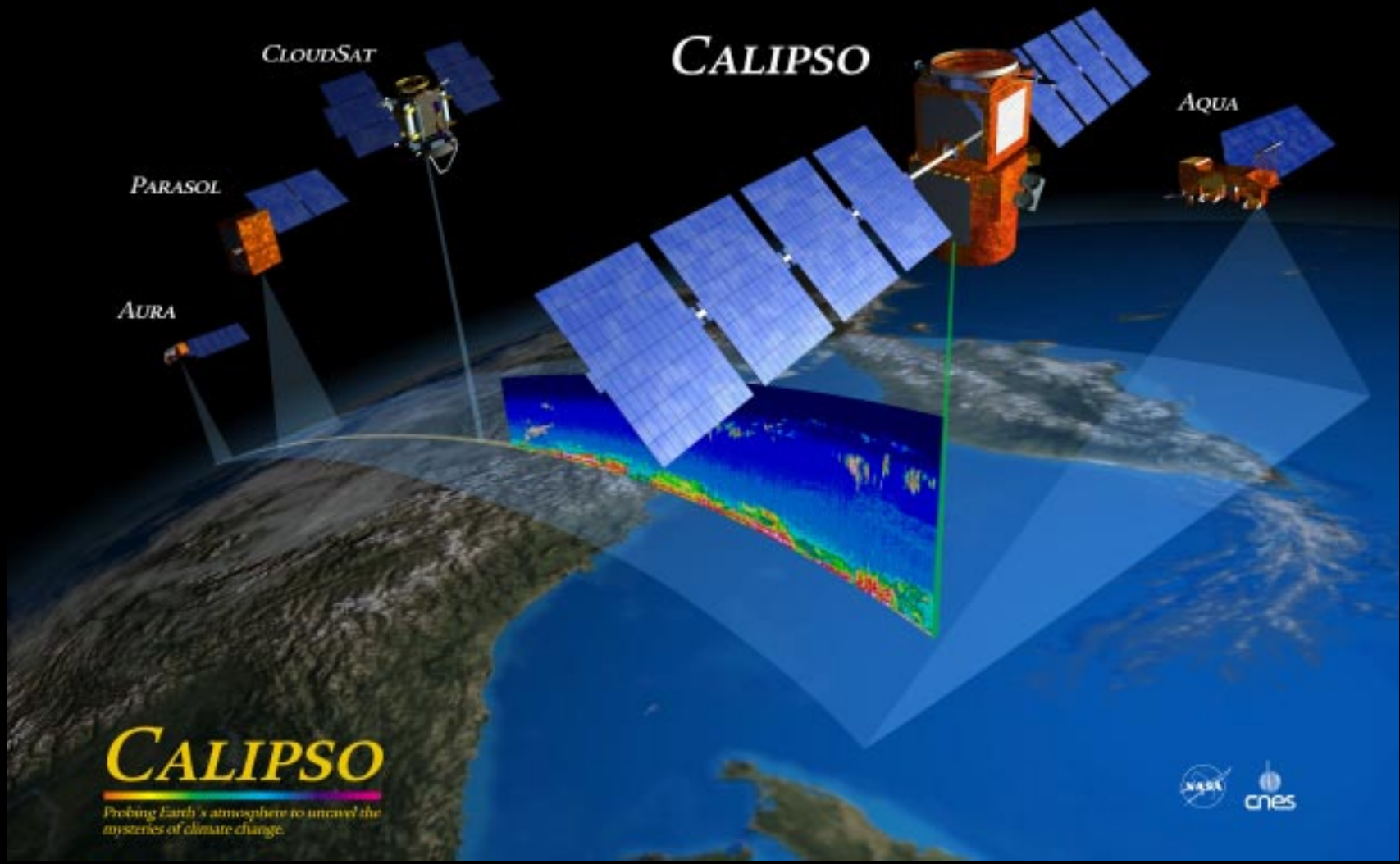
The Cloud/Climate Challenge



Better sampling

Better physics

“A-Train” Formation for Aerosol and Cloud Vertical Profiles
Atmospheric State => Aerosol/Cloud => Radiative Heating



But isn't this the tip of the iceberg?

- Yes. Oceans, ice sheets, carbon cycle, aerosols all remain critical issues as well.
- There currently is no rigorous climate observing system in place or yet planned.
  - we use well sampled weather data (but often lacks accuracy for climate, and misses many variables)
  - we use poorly sampled research data (often good accuracy but gaps or poor overlap)
- There is no single U.S. climate agency. Key contributors: NASA, NOAA, NSF, DOE, EPA.
- Cost of a climate system would be well beyond current US programs (factor of 5? $10B/yr?)
- Major change would require a "climate epiphany"…

A possible future

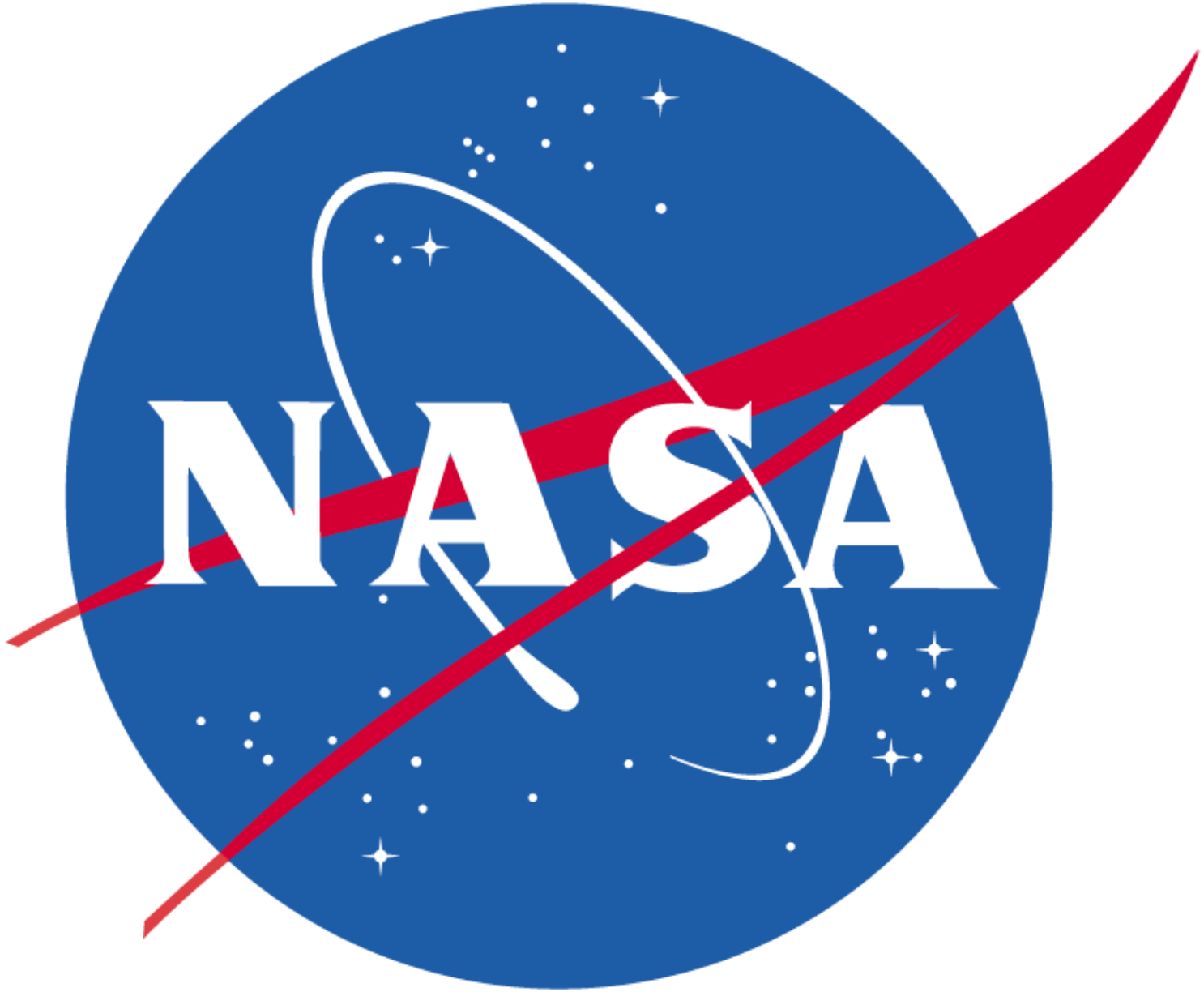
- **An international climate *mission*: analogous to Apollo or the Manhattan Project.**
  - **Implement rigorous and robust climate observations.**
  - **Comprehensive climate modeling efforts.**
  - **But no a-priori guarantees of success.**
- **What would we do with climate prediction certainty if we had it and climate change is predicted to be large?**
  - **Renewable energy development.**
  - **Energy conservation/efficiency.**
  - **Decadal plans for energy system transitions, land use change patterns, sea-level rise mitigation.**
  - **Vary response with regional changes.**
- ***Is human society capable of coordinated and planned action on global & decade time scales?***

"*Nature is a mutable cloud which is always and never the same*".

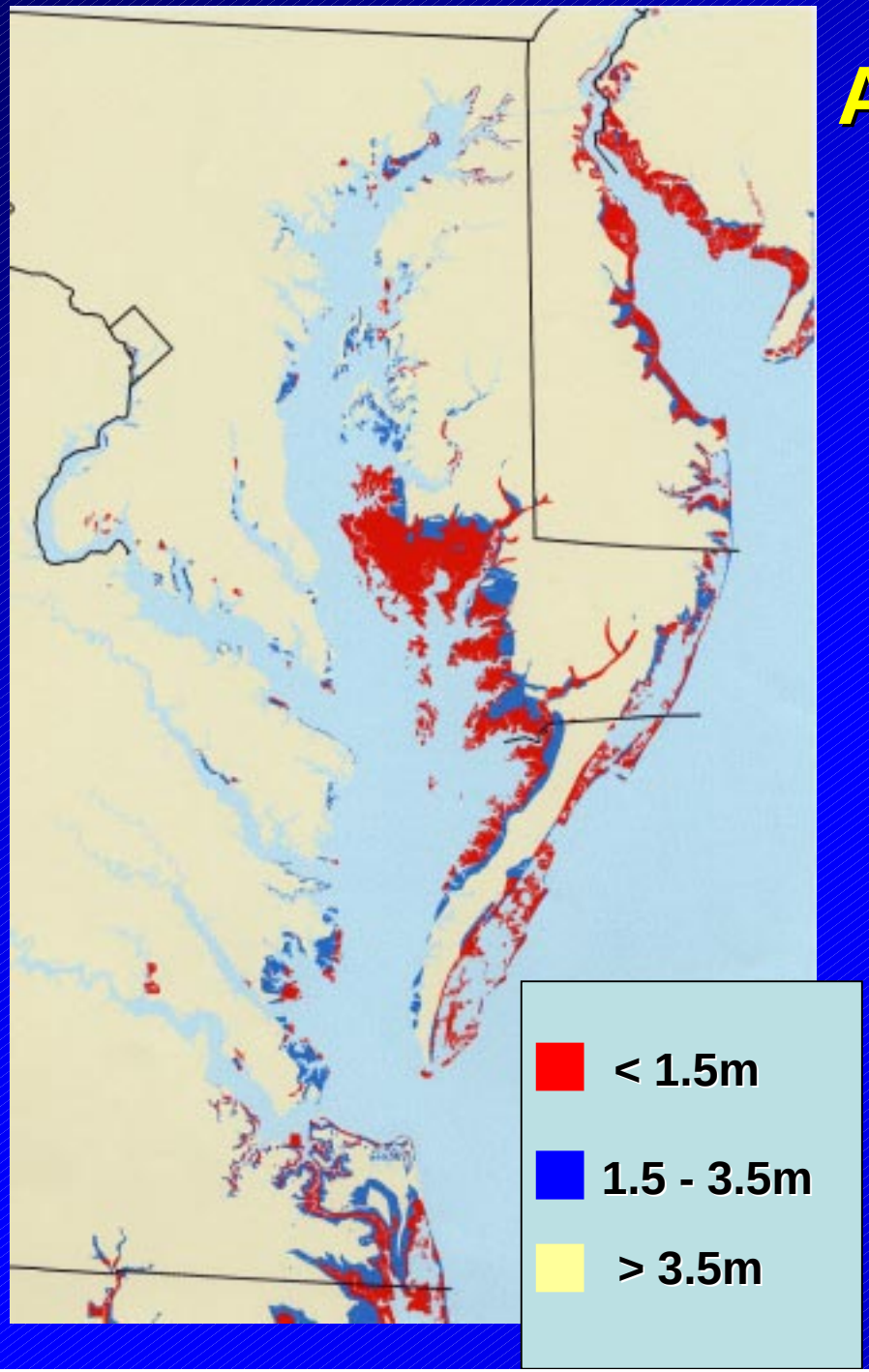
- Ralph Waldo Emerson (1803-1882)

"Man masters nature not by force, but by understanding."

- Jacob Bronowski, 1956


NASA

Altitudes above sea level Chesapeake Bay area



A large portion of Chesapeake & Delaware Bay wetlands would be inundated by 0.8-m rise in sea level

Beaches would be lost & new bridges would be required for newly formed islands

More areas would be exposed to storm surges